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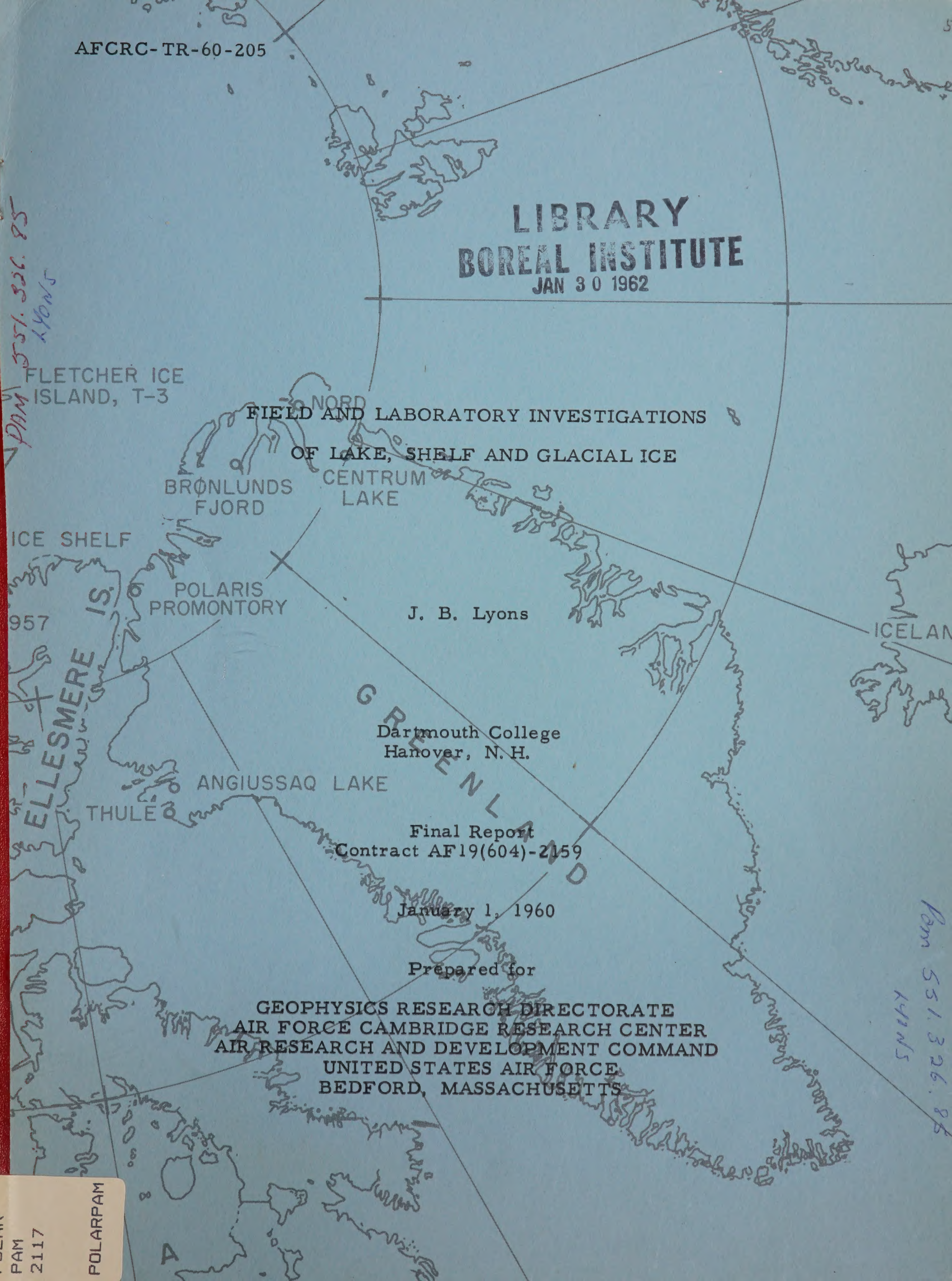

FIELD AND LABORATORY INVESTIGATIONS OF LAKE, SHELF AND GLACIAL ICE

J. B. Lyons

Dartmouth College
Hanover, N. H.

Final Report
Contract AF19(604)-2159

January 1, 1960

Prepared for

GEOPHYSICS RESEARCH DIRECTORATE
AIR FORCE CAMBRIDGE RESEARCH CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
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Introduction

This is a summary report, covering investigations which have been carried out by Dartmouth College during 1957-59 for the Geophysics Research Directorate of Air Force Cambridge Research Center. Most of the information contained herein has been condensed from a series of Scientific Reports, Quarterly Reports, and other papers submitted to the Air Force, in which the basic data and results are set forth in greater detail.

The project commenced, in 1957, with a field investigation of perennially frozen Angiussaq Lake, Northwest Greenland, as a possible year-round landing site. In 1958 further field investigations were undertaken on T-3, with the objective of relating surface geomorphology and ablation characteristics to the problem of stabilization of runways. In 1959 the college supported further investigations, at Lake Peters, Alaska, on the strength characteristics of melting lake ice; these latter studies were under the direction of the U. S. Geological Survey.

Two of the problems arising out of the field studies have been investigated experimentally. One of these is the absorption of radiant energy by melting ice; the other is the reason for the varying crystallographic orientations in lake ice.

Limnological investigations were begun under this contract at Angiussaq Lake, Greenland, and at Lake Peters, Alaska. This work, however, has been continued under the sponsorship of the Arctic Institute of North America. A study of the gases entrapped in glacial ice has also been partially supported through this contract, in cooperation with the Arctic Institute of North America.

Lake Ice Studies, Angiussaq Lake, Greenland

This perennially frozen lake, 60 miles northeast of Thule, Northwestern Greenland, was chosen as a test site to check the possibility of using such high Arctic lakes for year-around aircraft operation.

The lake ice provides a potential runway at least 3 1/2 miles long. During the summer, ablation decreases the ice thickness from 11 to 5 1/2 feet, but in-place cantilver beam tests indicate minimal breaking strength of 20-30 psi - or enough to support loads of 100,000 pounds spread out over a two-foot diameter loading area. Even at the height of the melt season the ice has sufficient strength to support heavy aircraft such as the C-124 and the C-130. However, imperfections such as sastrugi, rock piles and boulders, holes and open leads develop during the melt season, and make the surface unsafe for landings during this time.

Angiussaq Lake would provide a safe landing platform for heavy aircraft for at least 9 months of the year. It probably could also be made operational during the summer, but this would first necessitate further strength testing, and an evaluation of ice surface improvements by such techniques as smoothing with bulldozer, flooding, removing rock piles, etc.

The strength determinations at Angiussaq Lake have been summarized, by D. F. Barnes, AFCRC geophysicist, in a series of internal reports, and also in one formal publication (Barnes, 1958). Descriptions of the geological history of the lake and of the textural and structural characteristics of its ice have been prepared by Taylor (1958) and Taylor and Lyons (1959).

Investigations at T-3

Geomorphology and hydrology of the two square mile Opportunity Creek area on T-3 were studied intensively during a 31/2 month period in the summer of 1958, under the direction of D. D. Smith. Emphasis was placed on the progressive variation in and development of the morphology of the ice surface.

Work consisted of the mapping of ice stratigraphy and structure, ablation measurements, and hydraulic discharge determinations. Three major ice types were mappable at the surface of T-3 - firn, old lake ice, and young lake ice.

The picture which has evolved from this study is that the surface morphology shifts continuously as progressively deeper levels of the ice island are exposed. Because of their higher albedo, areas which are underlain by lake ice (and were, therefore, formerly depressions) now tend to ablate more slowly than the surrounding firn. As a consequence, the topography of the surface of ablation tends to develop into a mirror image of the initial surface of accumulation; there is, in other words, an inversion in relief. These considerations become important in planning future installations on T-3, and in trying to devise methods for preserving and diverting drainage around its present runway.

Topographic profiles, ablation graphs, etc. have been prepared from the 1958 field data, and a final summary report has been prepared by Smith (1960).

Lake Ice Investigations, Lake Peters, Alaska

Further studies on the strength characteristics of melting lake ice have been carried out by D. F. Barnes of the U. S. Geological Survey, with the assistance of Frank Leavitt of the Dartmouth Geology Department.

The study site was Lake Peters, Alaska, where tests were conducted from May to August of 1959.

The unique result of Barnes' research has been to show the strong inter-relations between crystallographic orientation and strength of the melting lake ice. Those areas of Peters lake in which the ice crystals have a predominantly vertical c-axis orientation are far stronger and rot much more slowly than ice areas in which the c-axes are predominantly horizontal. These differences are related to the development of Tyndall figures in the melting ice, and the fact that the albedo of ice with horizontal Tyndall figures (and vertical c-axes) is much higher than that of ice with vertical Tyndall figures (and horizontal c-axes).

Barnes' (1960) preliminary summary of the Lake Peters studies is soon to be published.

Laboratory Studies on Ice Orientation

Barnes' studies (see above) have pointed up one of the important consequences of the fact that lake ice has variable crystallographic orientations. Because the reasons for this variability were poorly understood, a laboratory study of the phenomenon was carried out at Dartmouth during the interval from June through December of 1958. Water was frozen in plastic containers under varying conditions and directions of thermal flux, and also under variable wind conditions. Our results indicate that any or all of the following factors help determine the direction of preferred growth for fresh water ice crystals: (1) thermal gradient in the growth medium, (2) thickness of the supercooled water layer, (3) fragmentation (by wind, for example) of the early-formed ice layer, and (4) more rapid velocity of crystallization in the basal plane of ice.

Results of the laboratory investigation of the orientation of lake and artificial ice have been published in a report by Lyons and Stoiber (1959).

Laboratory Investigation of the Absorptivity of Ice

Large uncertainties in the published literature on the absorption of radiant energy by ice, and the consequent uncertainty concerning the magnitude of this effect in the melting and ablation of ice have prompted a re-evaluation of this fundamental parameter. Laboratory measurements were made on ice up to 11 cm. in thickness and in the spectral range from 400 to 1200 mu. A Welch photoelectric densichron detector was the recording instrument.

Our readings indicate that for clear flawless ice Sauberer's (1950) carefully determined values are probably the best available, and that there is very little difference in the absorptivities of ice and water. The infrared absorption bands in ice are slightly offset toward the higher wavelengths.

Most natural ice is bubbly, and therefore scatters incident radiation. Its absorption coefficients in the visible spectral range generally lie between .015 and .050 cm.^{-1} - that is, an order or two of magnitude larger than absorption coefficients for clear ice.

The absorption caused by grain boundaries is evidently very small, and is not detectable by our instruments. It is also possible to demonstrate that there is no anistropy in the absorptivity of ice, contrary to the generally accepted data in the literature.

A fuller discussion of the absorptivity of ice has been published by Lyone and Stoiber (1959) as a part of this contract.

Limnological Studies

Because so little is know of the limnology of arctic lakes, studies in this discipline were initiated at Angiussaq Lake under the direction of John Hobbie. Work during the 1957 field season resulted in establishing the morphometry of the lake basin, determining depth-temperature profiles, carrying out oxygen determinations, and making observations on the ecology of the lake.

Hobbie's work on the limnology of arctic lakes was continued, under this contract, at Lakes Schrader and Peters, Alaska, during the 1958 field season. In 1959, sponsorship was taken up by the Arctic Institute of North America.

Lakes Schrader and Peters are on the north slopes of the Brooks Range, at an elevation of 2793 feet, and lie in a valley which has undergone three periods of glaciation. The former lake has an area of 5.1 square miles and an average depth of 140 feet; the latter's area is 2.6 square miles, and its average depth 125 feet. Both lakes are ice covered for 10 months of each year. Because of a heavy concentration of rock flour, approximately 90% of solar radiation is absorbed in the uppermost meter of the Lake Peters waters; in Lake Schrader, which is clear, the depth corresponding to 90% absorption (10% transmission) is 5 meters. Temperature profiles made at both lakes indicate a strong mixing effect by the wind, so that no thermocline is developed at any time. This same mixing effect also is apparent from the pH values (uniformly between 5.5 and 6.0 in all parts of the lakes) and the fact that the lake waters are oxygen-saturated. The lakes are biologically fertile, despite the short summer, and collections have been made of phytoplankton, crustaceans, insect larvae, worms, and fish (grayling, Arctic charr and lake trout).

A final report on the limnology of Lakes Peters and Schrader has been submitted by Hobbie to AFCRC, through the Arctic Institute of North America.

Gas Enclosures in Glacial Ice

Partial support has been extended, under this contract, toward an investigation of gas enclosures in glacial ice. The project had major support from the Arctic Institute of North America, and David Nutt was the participating scientist from Dartmouth College.

Field investigations were conducted on board the Norwegian seal-hunter M/S Rundy in West Greenland waters between Melville Bay and Brede Fjord during the summer of 1958. Large samples of glacial ice issuing from Greenland glaciers were analyzed aboard ship for salinity and for gas composition, volume and pressure. In eleven samples CO_2 was extracted for C_{14} dating and numerous samples are being processed for analysis of carbon, argon and $0^{16}/0^{18}$ ratio. The objective of the above studies is to test the possibility of detecting climatic variations in the past on the basis of the composition of the entrapped gases in glacial ice, it now being known that the initial 0^{18} content of glacial ice is dependent on altitude and temperature. It is also hoped that these studies may throw light on the question of the source areas for the presently calving icebergs, and may contribute to an understanding of the $0^{16}/0^{18}$ changes which accompany the melting, freezing, or metamorphism of ice.

Dielectric Determination of the Liquid Water Content of Ice

In making determinations of the strength of ice at or near its melting point, one of the parameters which is undoubtedly significant, but very difficult to determine accurately, is the liquid water content of the ice. The standard techniques (i. e. calorimetry, or the freezing point depression method) are not only liable to increased error under field conditions, but are also beset with the disadvantage that the sample must be removed from its natural habitat before the determination can be made. How much water is gained or lost during this exchange becomes very uncertain.

The great differences in the dielectric constants of water and ice, particularly at high field frequencies, suggested that an apparatus might be devised which would allow an in situ measurement of the liquid water content of ice. Professor H. W. Curtis of the Thayer School of Engineering at Dartmouth undertook a study of the feasibility of such instrumentation.

Curtis has carried out a theoretical study of the effects on dielectric measurements of various possible geometric arrangements of ice and water. He has concluded that such geometrical factors will introduce unacceptably wide uncertainties in the interpretation of any dielectric measurements made on ice-water mixtures. For this reason, further efforts in this type of instrumentation were suspended.

Curtis' report on the possibility of dielectric measurements for determining liquid water content of ice has been submitted as a portion of Quarterly Report No. 8 of this contract.

References Cited

Barnes, D. F., 1958, Preliminary measurements on the strength of melting lake ice: Trans. Eng. Inst. Canada, v. 2, p. 108-111.

Barnes, D. F., 1960, Lake Peters ice studies: Proc. Second Annual Arctic Planning Conference; Geophysics Research Directorate, Air Force Cambridge Research Center (In preparation)

Curtis, H. W., 1959, On the feasibility of dielectric measurements for determining the liquid water content of ice: Quarterly Report #8; Contract AF 19(604)-2159 with Geophysics Research Directorate, Air Force Cambridge Research Center.

Lyons, J. B. and Stoiber, R. E., 1959, Crystallographic orientation in lake and artificial ice: Scientific Report #2; Contract AF 19(604)-2159 with Geophysics Research Directorate, Air Force Cambridge Research Center

Lyons, J. B. and Stoiber, R. E., 1959, The absorptivity of ice: a critical review: Scientific Report #3; Contract AF 19(604)-2159 with Geophysics Research Directorate, Air Force Cambridge Research Center.

Sauberer, F., 1950, Die Spektrale strahlungdurchlassigkeit des Eises (The spectroscopic transparency of ice): Wetter u. Leben, v. 2, p. 193-197

Smith, D. D., 1960, Development of surface morphology on Fletcher's Ice Island, T-3: Scientific Report #4; Contract AF 19(604)-2159 with Geophysics Research Directorate, Air Force Cambridge Research Center

Taylor, L. D., 1958, Ice petrofabrics, Angiussaq Lake, Northwestern Greenland: M. A. Thesis, Dartmouth College, 76 p.

Taylor, L. D. and Lyons, J. B., 1959, Ice structures, Angiussaq Lake, Northwest Greenland: Scientific Report #1, Contract AF 19(604)-2159 with Geophysics Research Directorate, Air Force Cambridge Research Center

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